

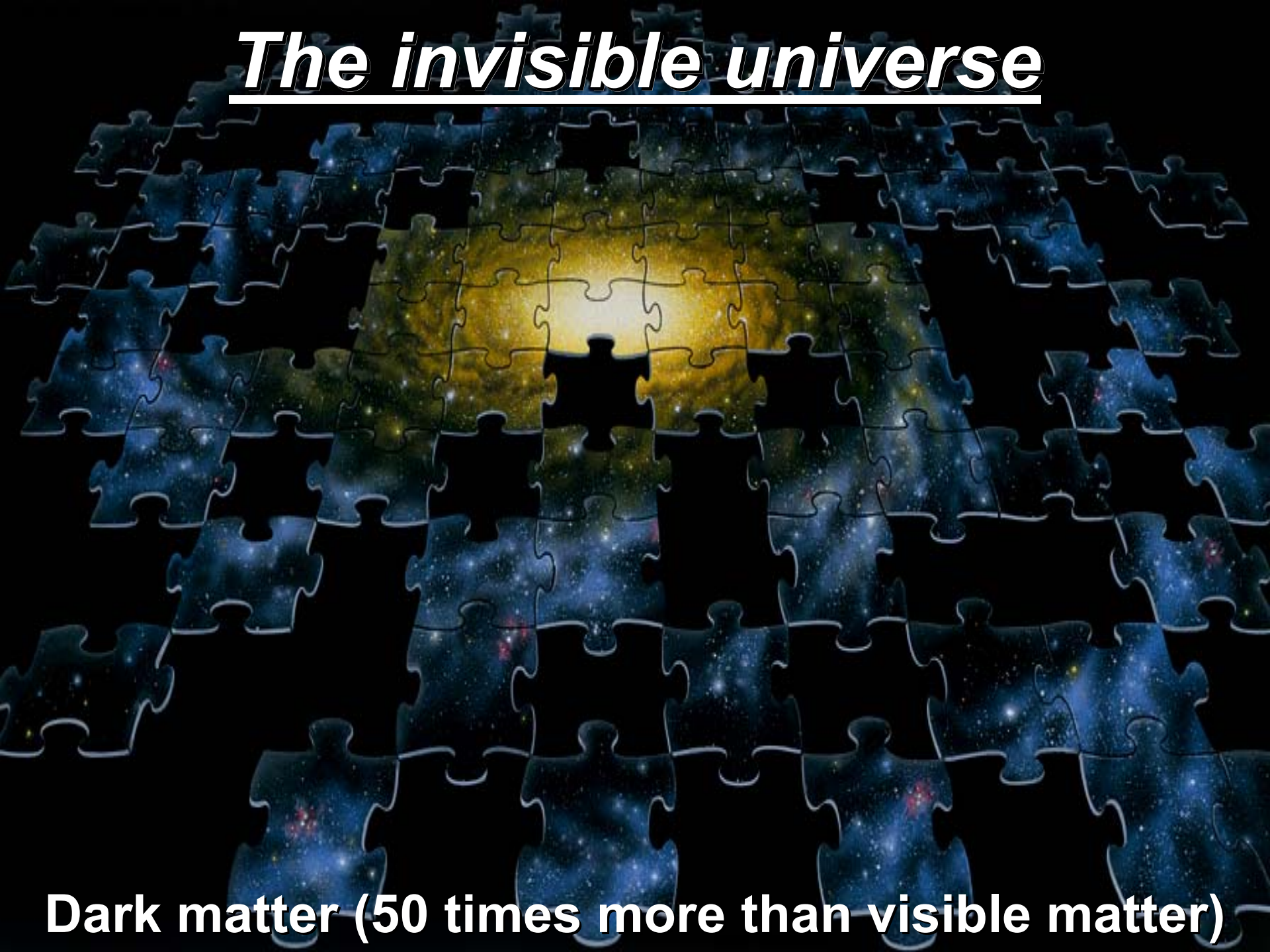
Lecture 16 May 27, 2004

Much ado about nothing

News of the week

- Regular office hours Tuesday & Thursday (next week also)
- Lab this week: The mass density of the Universe
- Finish reading Hawking
- Lectures:
 - May 27th: Much ado about nothing & the first second
 - June 1st: It's about time
- Final Exam: Tuesday, June 8th, 10:30am-12:30pm
- Course evaluations today

The invisible universe



Dark matter (50 times more than visible matter)

Dark energy?

Space and time are related.

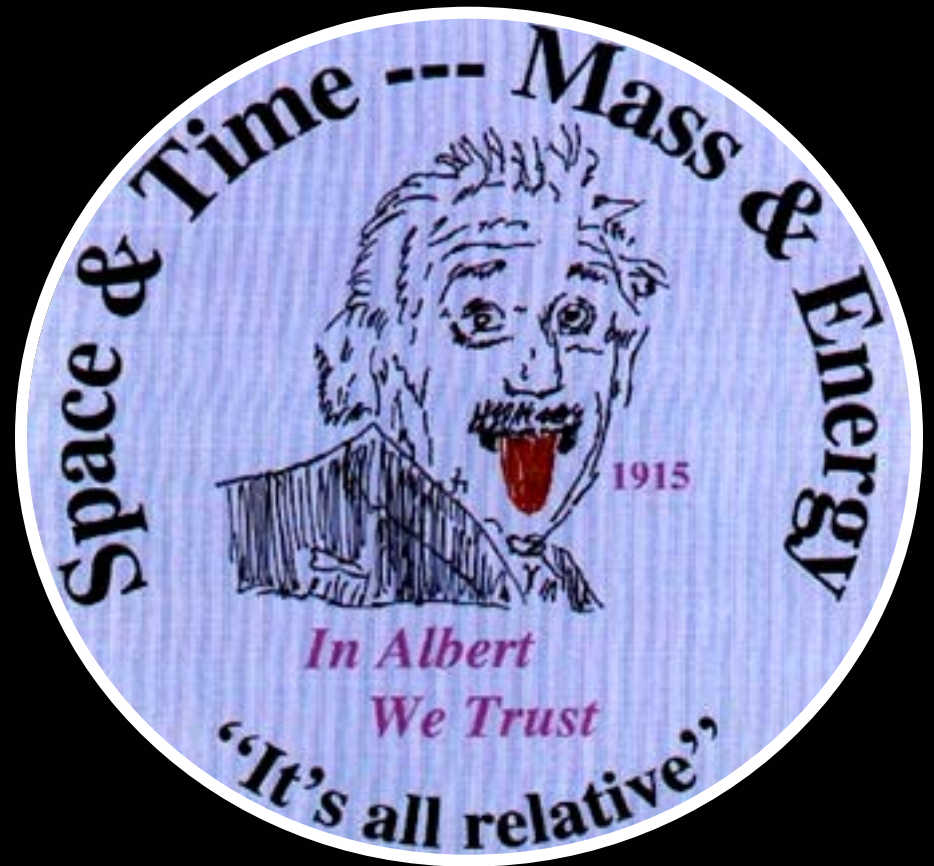
1905

Space is dynamical
(curved, warped, bent).

1915

Empty space has a weight.

1917





the weight of space

Cosmological
constant

(Dark energy)

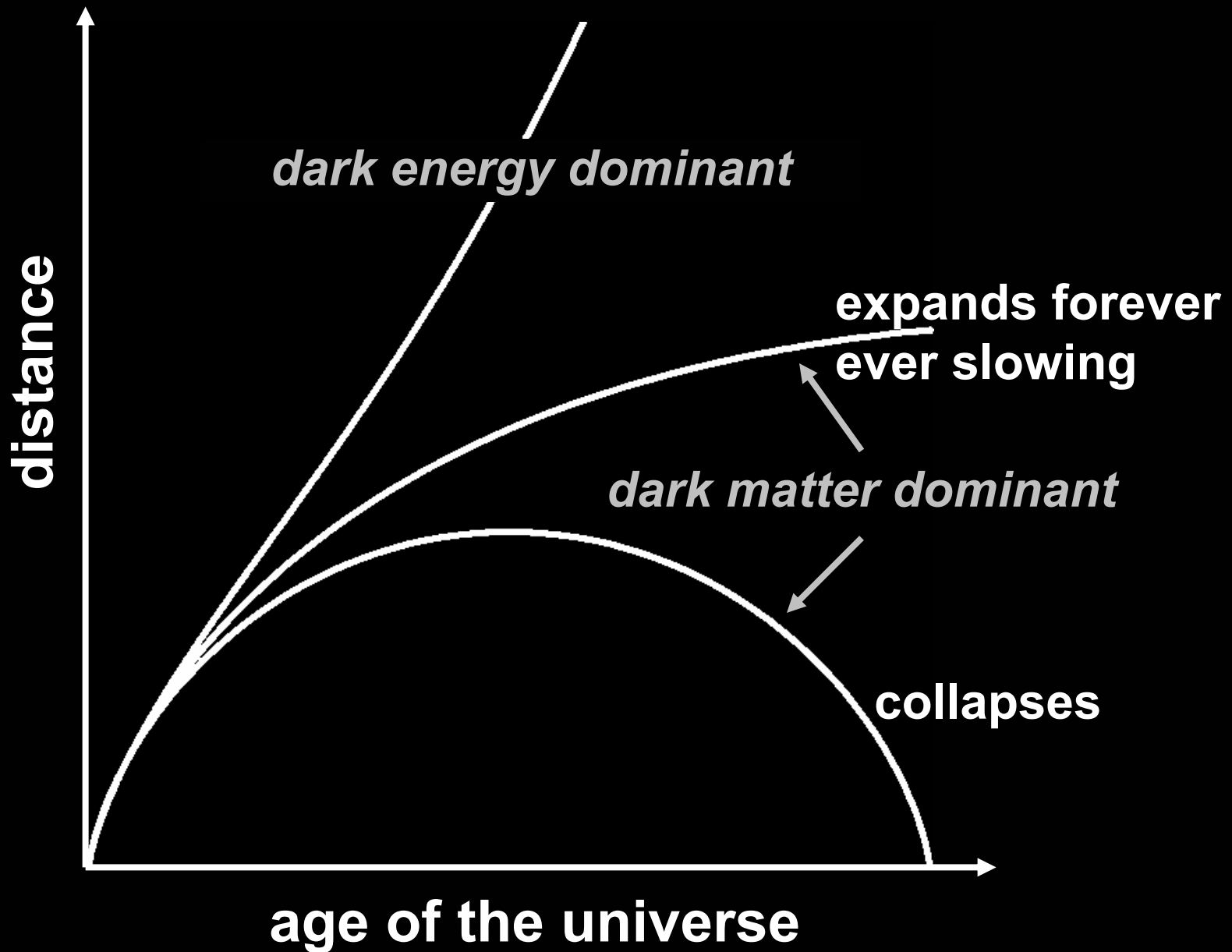
1917 Einstein proposed cosmological constant.

1929 Hubble discovered expansion of the Universe.

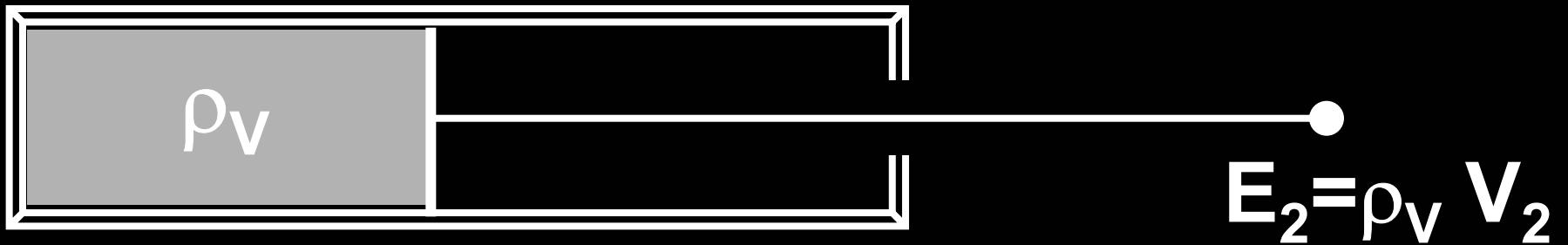
1934 Einstein called it “my biggest blunder.”

1998 Astronomers found evidence for it.

Cosmological constant (dark energy)



Vacuum pressure



$$E_2 > E_1$$

had to pull piston
“negative pressure”

Gravitational potential energy (negative since force is attractive)

$$V = -\frac{GM}{R}$$

Einstein says that kinetic energy gravitates so pressure important

$$V = -\frac{G(M + 3p)}{R}$$

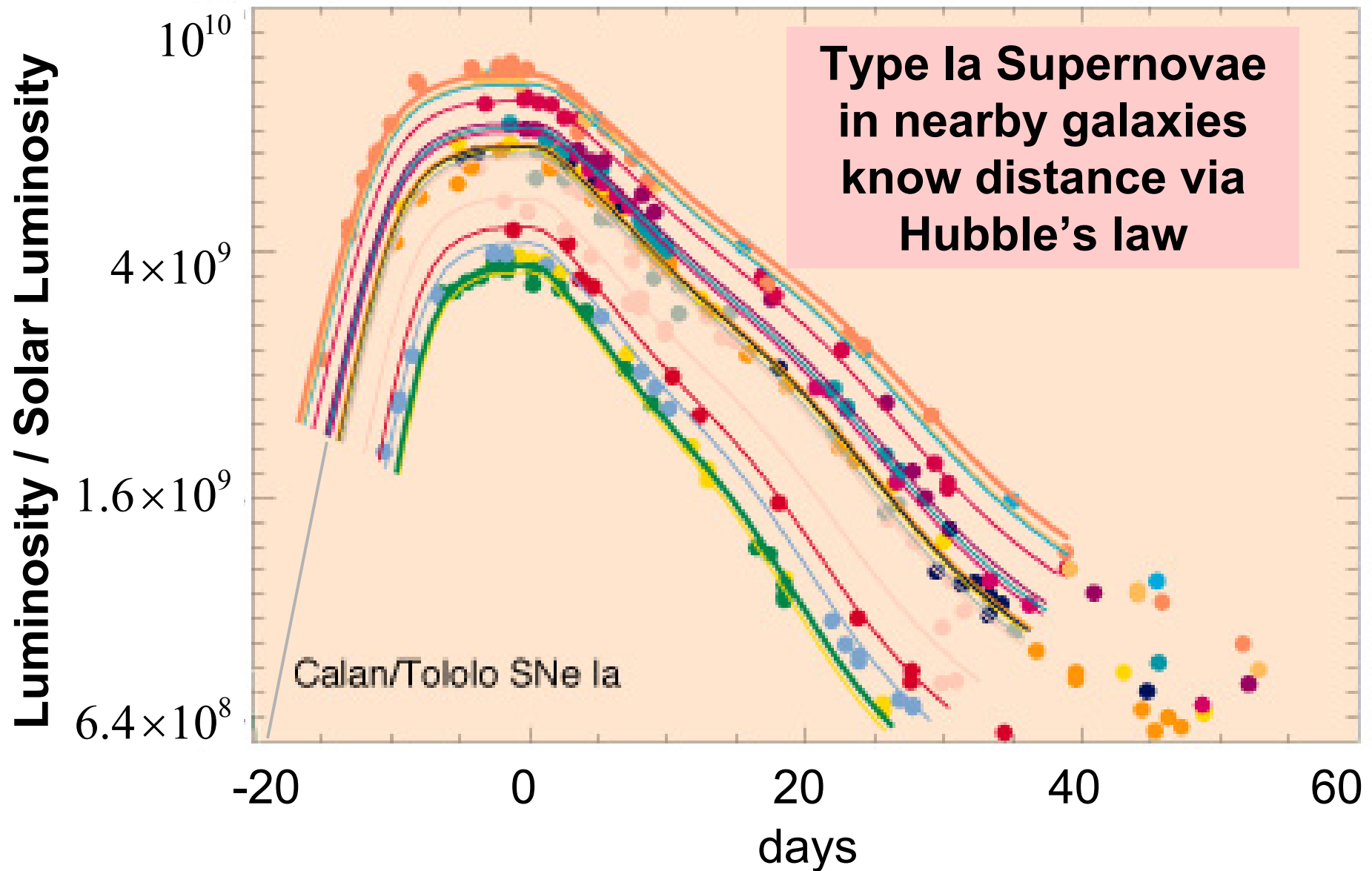
Vacuum energy has negative pressure (force is repulsive)

SN 1987A in the LMC

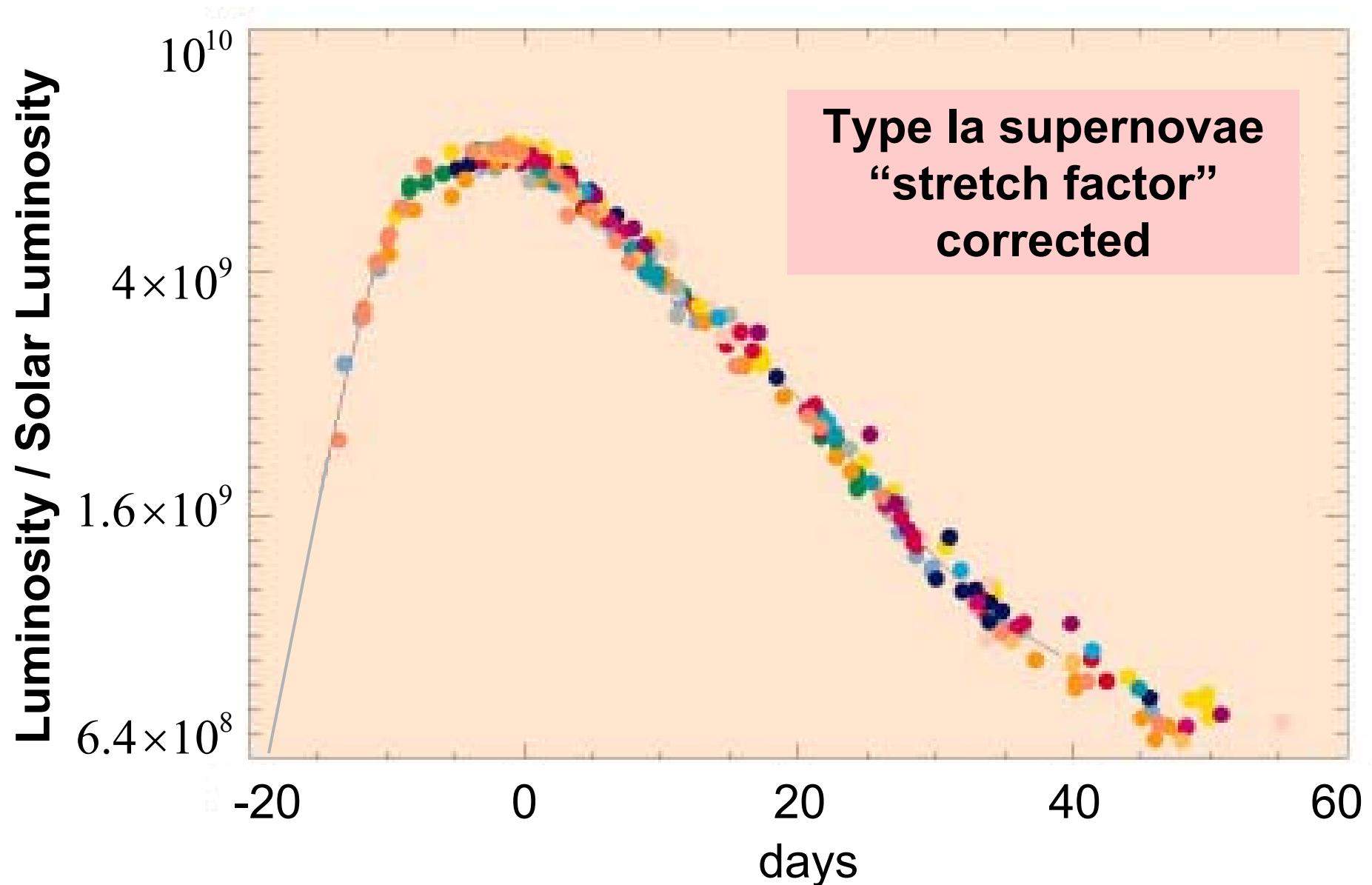
© Anglo-Australian Observatory



Type Ia supernova are standard candles

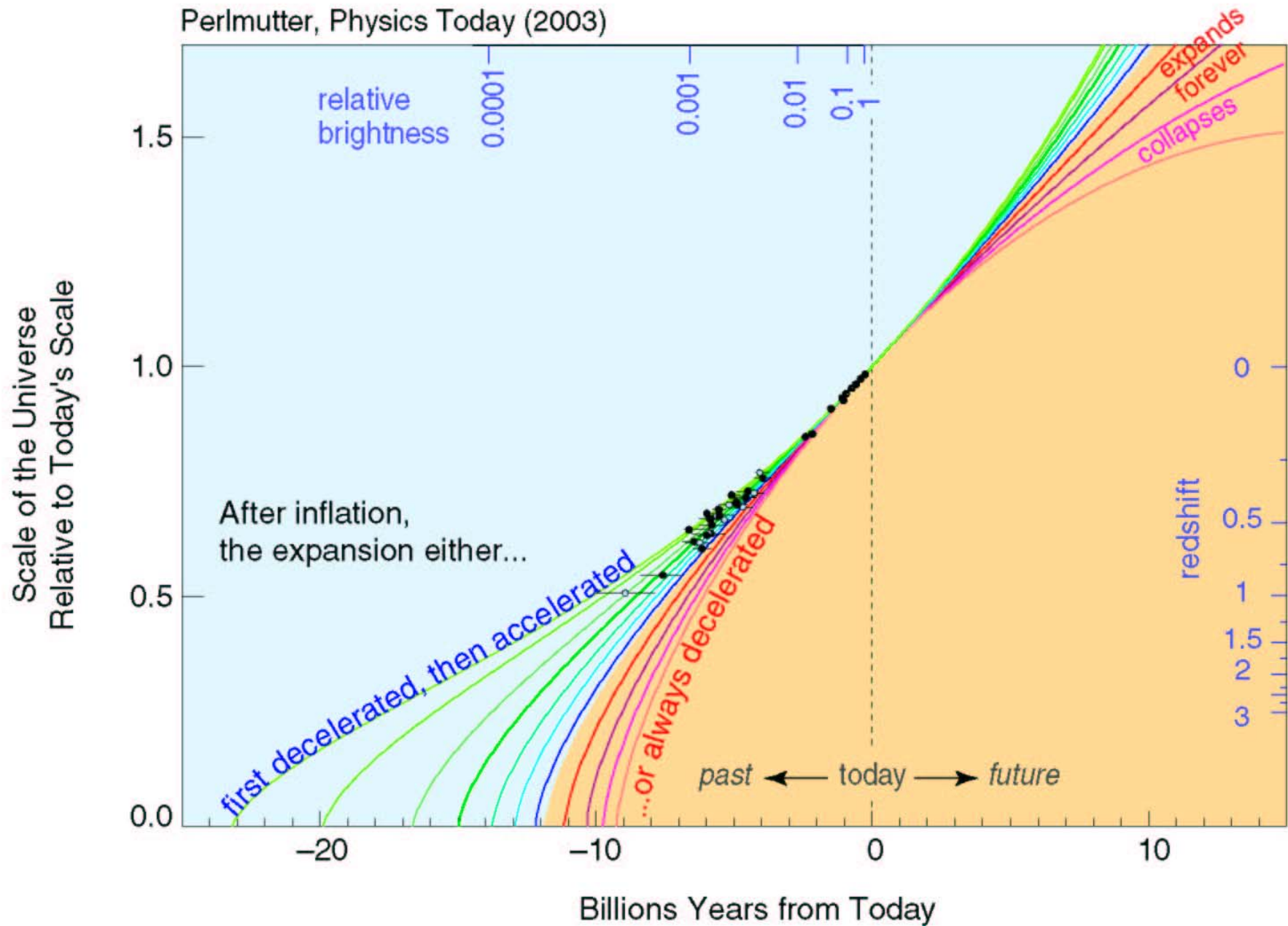


Type Ia supernova are standard candles

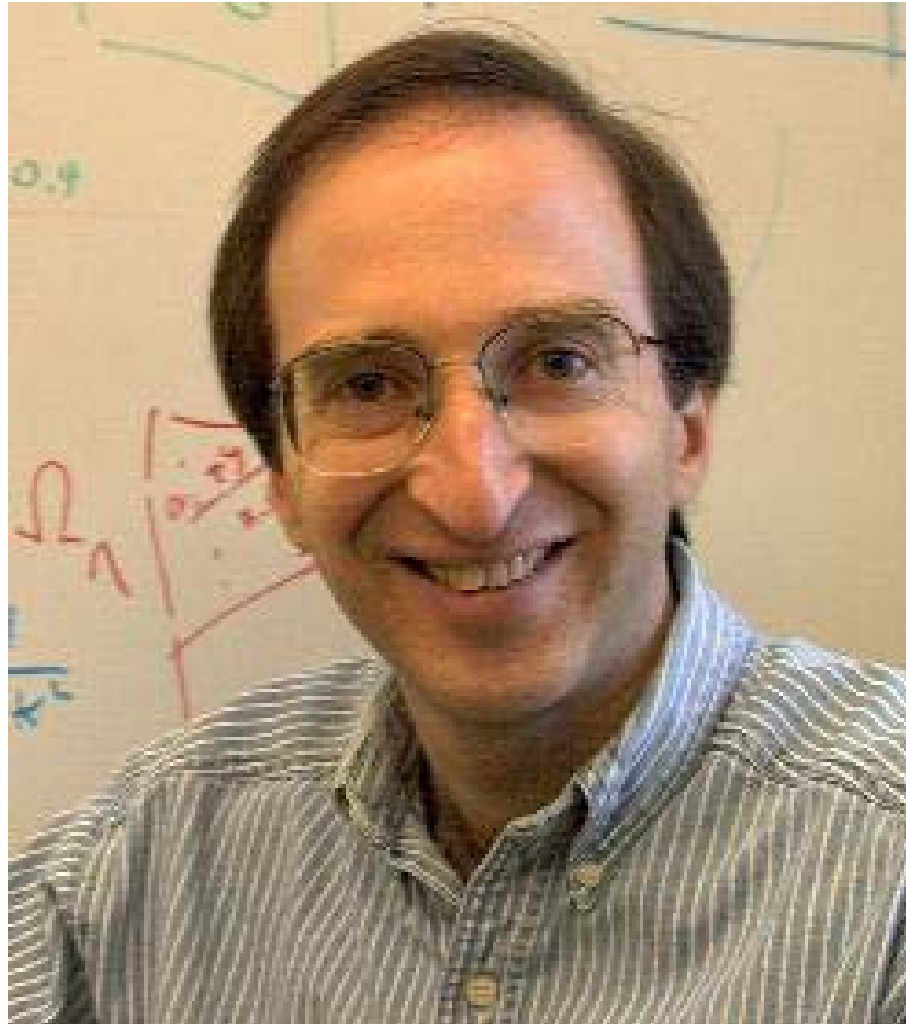


Expansion History of the Universe

Perlmutter, Physics Today (2003)

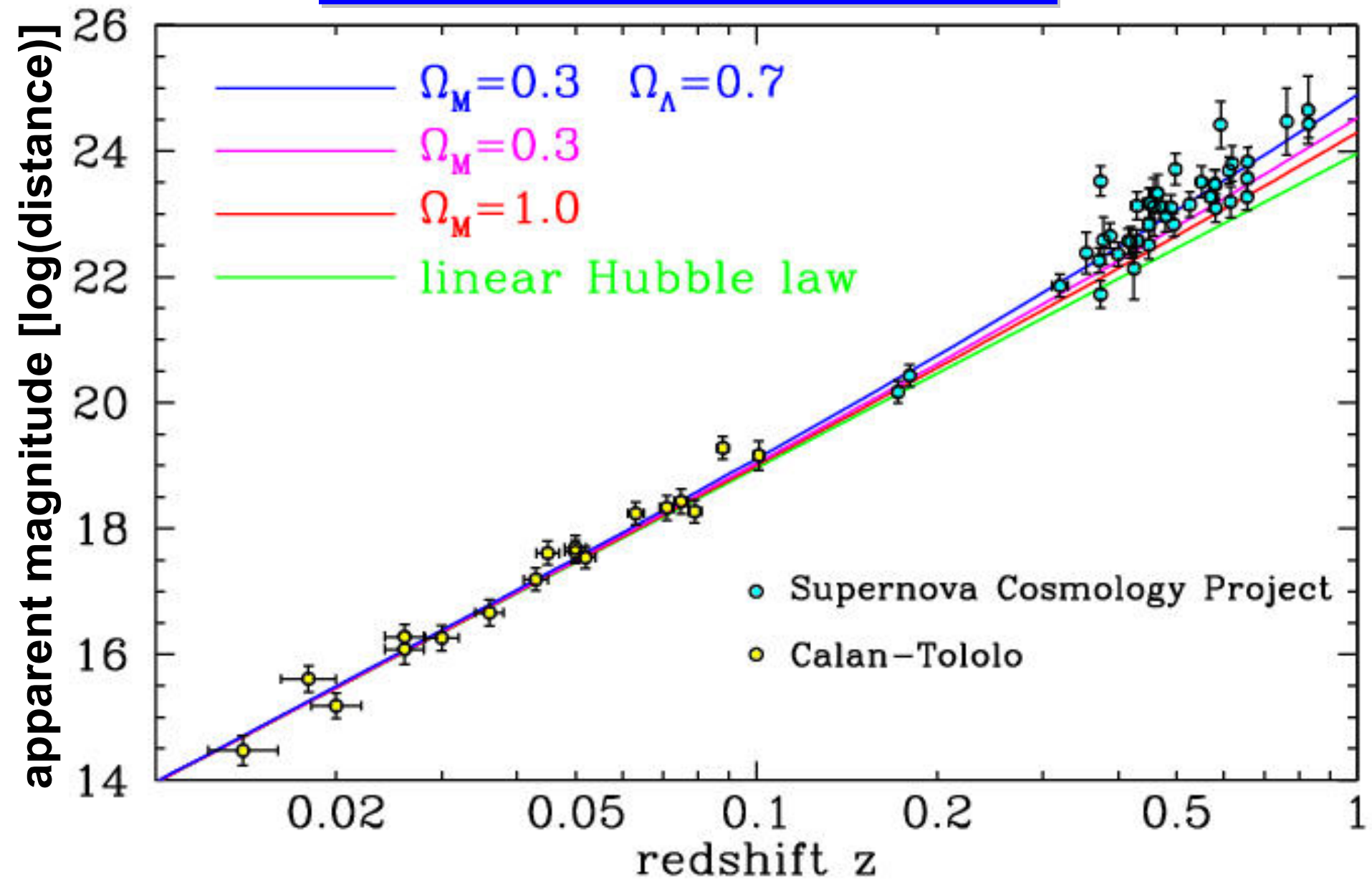


Saul Perlmutter

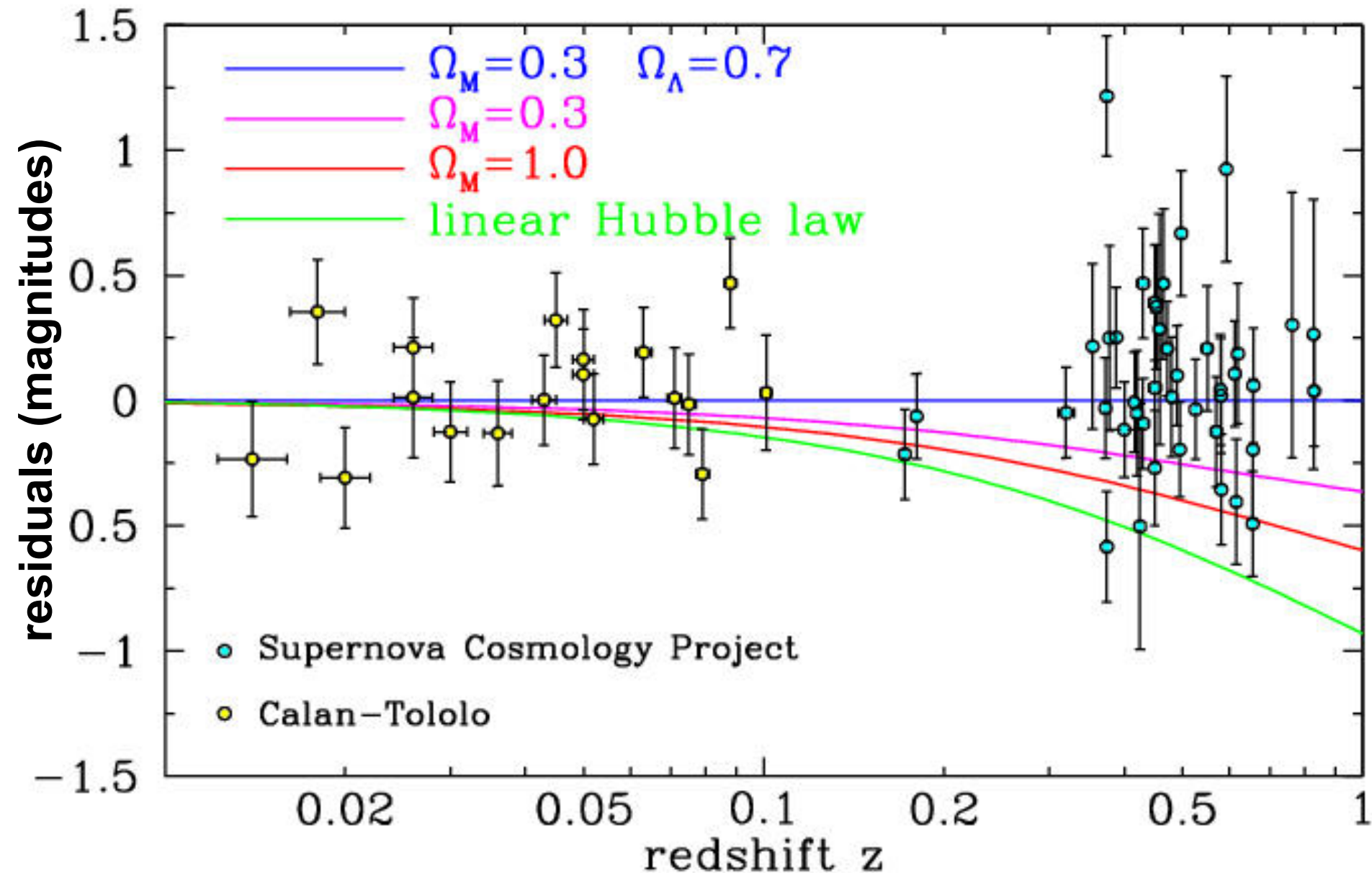


Supernova Cosmology Project

Type Ia supernova



Type Ia supernova



Cosmological constant ***(Dark energy)***

Mass density of space: $10^{-30} \text{ g cm}^{-3}$

The unbearable lightness of nothing!

Cosmo-illogical constant?

Much ado about nothing
(the quantum vacuum)

NOTHING is something!

WARNING!!

This remark may be

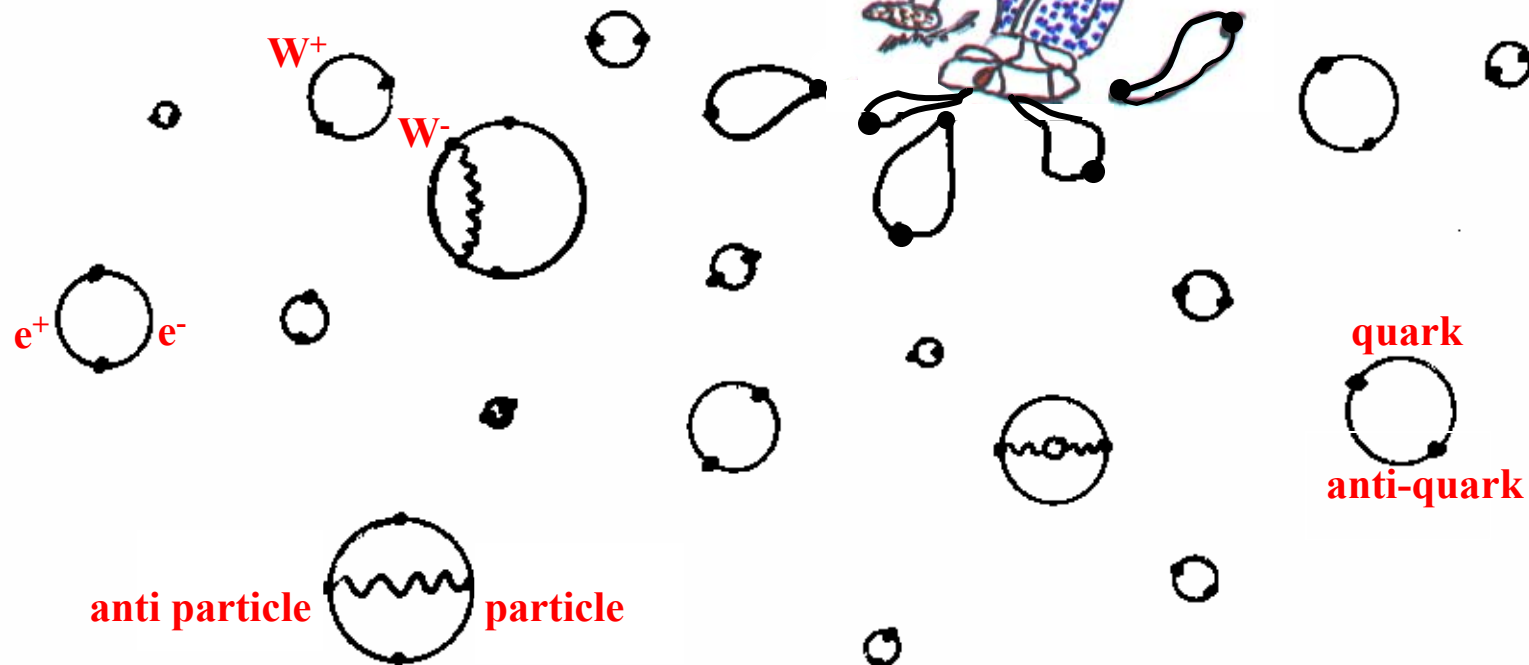
POLITICALLY INCORRECT!!

And possibly offensive to a
minority of slightly more
than 50% of the population



Uncertainty in the

Quantum Vacuum



Nothing is something!

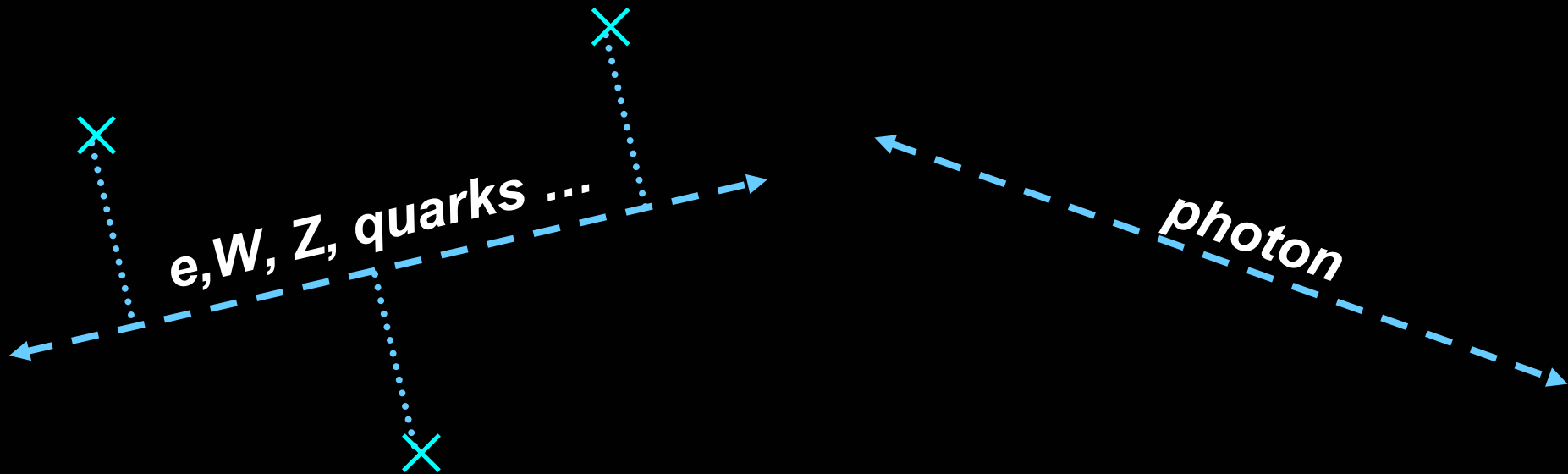
Much ado about nothing
(the quantum vacuum)

NOTHING is something!

NOTHING has energy!

The Higgs potential

- The quantum vacuum has a Higgs potential
- Higgs field potential gives mass to quanta like quarks and electrons.

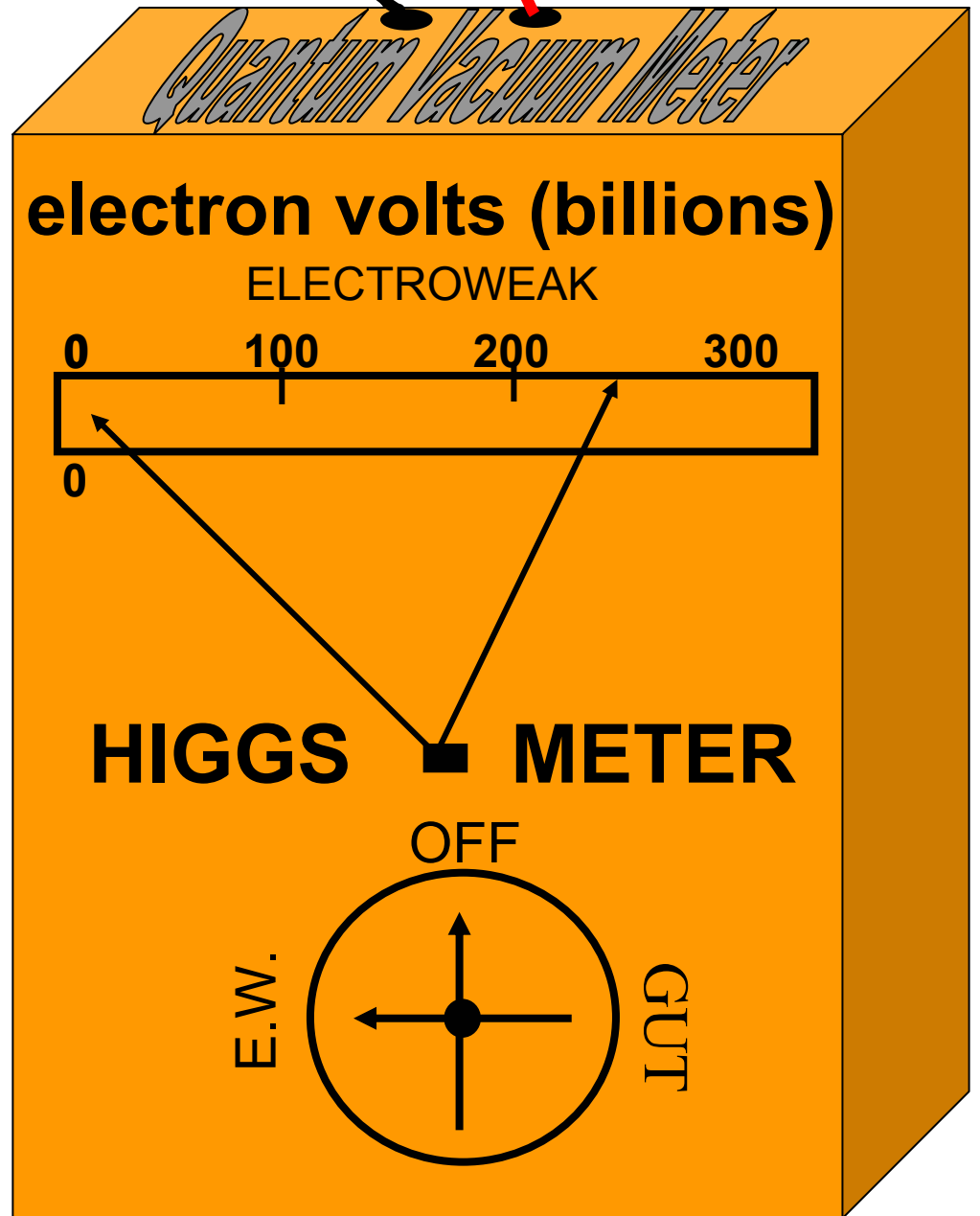


Nothing has energy:

Rocky discovers Higgs!



Prof. Peter Higgs



Nothing
has energy!

Energy of the quantum vacuum

Observed:	$\rho \leq 10^{-30}$	g cm^{-3}
Quantum field theory:	$\rho = \infty$	g cm^{-3}
Quantum gravity:	$\rho = 10^{+90}$	g cm^{-3}
Supersymmetry:	$\rho \leq 10^{+30}$	g cm^{-3}
Higgs potential:	$\rho \sim -10^{+25}$	g cm^{-3}
Other sources:	$\rho \sim \pm 10^{+20}$	g cm^{-3}

What do Martha Stewart and Saul Perlmutter have in common?

Martha Stewart



**America's
foremost
homemaker**

1. Can whip up a wicked soufflé?
2. Convicted felon?
3. Were high-school sweethearts?
4. Like younger men?
5. Use standard candles?
6. Use scented candles?
7. Use organic herbs?
8. Smoke organic herbs?
9. Subject of made-for-TV movie?
10. Benefit from a cosmic coincidence?

Saul Perlmutter



**America's
foremost
astronomer**

What do Martha Stewart and Saul Perlmutter have in common?

Martha Stewart



Saul Perlmutter

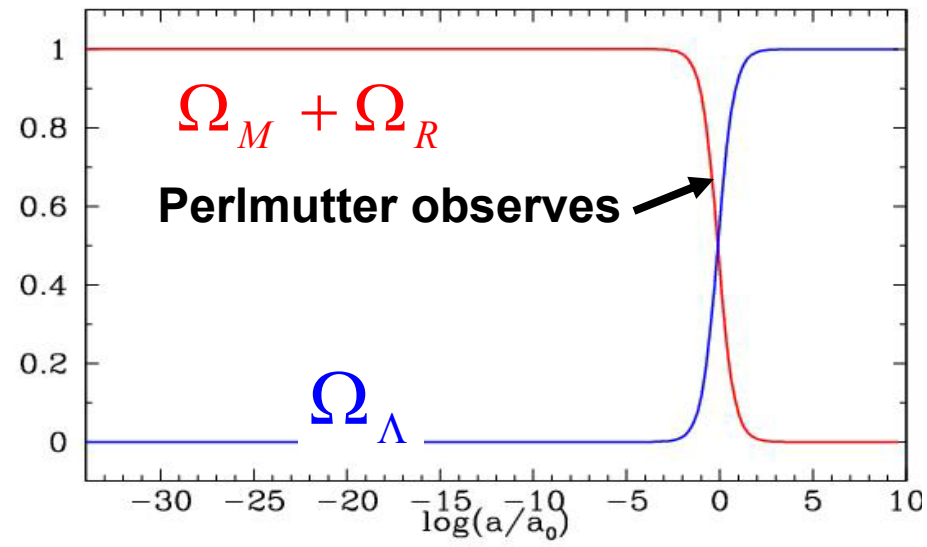


Cosmic coincidences!

ImClone stock price



Evolution of Ω_Λ



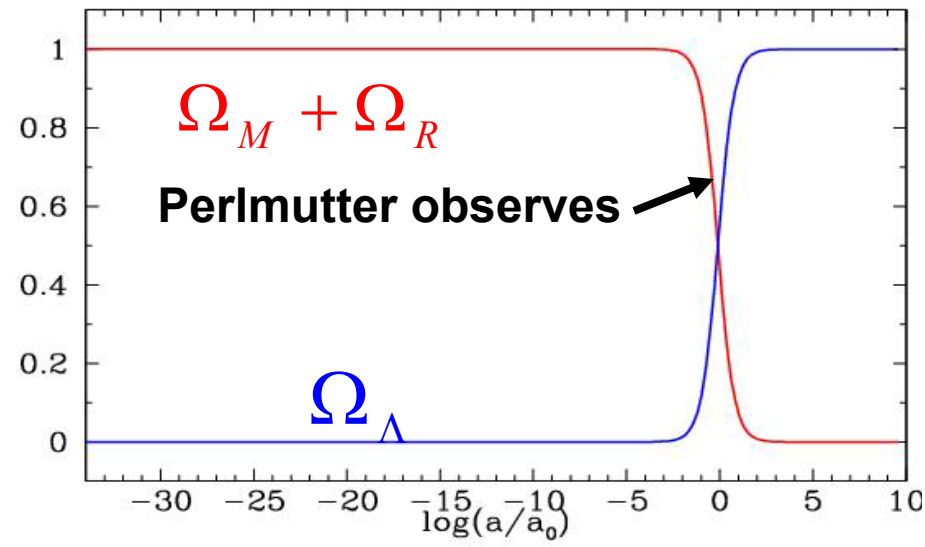
Cosmic Coincidences

- Should be regarded with skepticism
- Require an explanation
- Must be investigated
- Prosecution of guilty parties (if wrongdoing)

ImClone stock price



Evolution of Ω_Λ



Cosmic Coincidence

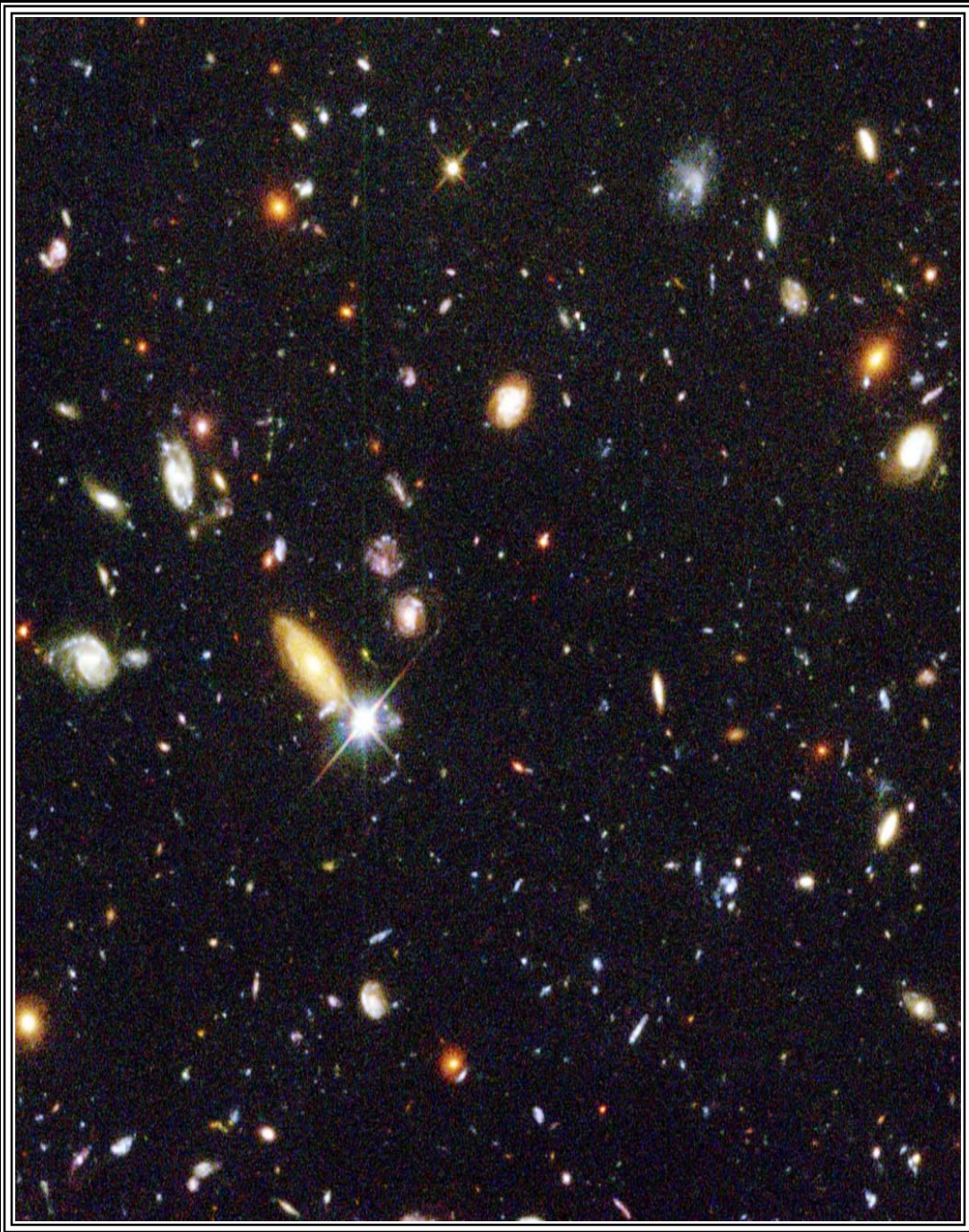
$$\rho_{\Lambda} \sim \rho_{DM} \sim \rho_B \sim \rho_{B-VISIBLE} \sim \rho_{B-DARK} \sim \rho_{\nu}$$

Much ado about nothing
(the quantum vacuum)

NOTHING is something!

NOTHING has energy!

NOTHING matters!



**“To me every hour
of the light and
dark is a miracle.
Every cubic inch
of space is a
miracle.”**

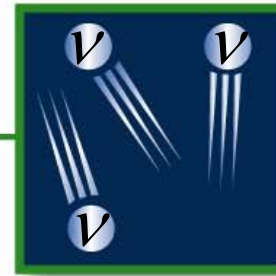
– Walt Whitman

- cosmic radiation**
- virtual particles**
- Higgs potential**
- dark matter**
- dark energy**

Cosmic Pie



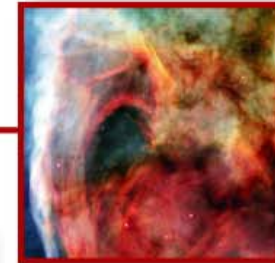
**Chemical Elements:
(other than H & He) 0.03%**



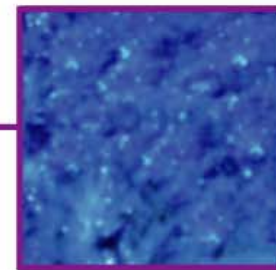
**Neutrinos:
0.47%**



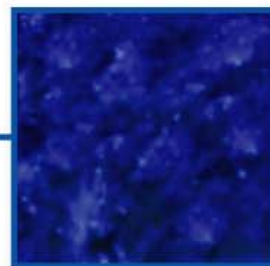
**Stars:
0.5%**



**Free H
& He:
4%**

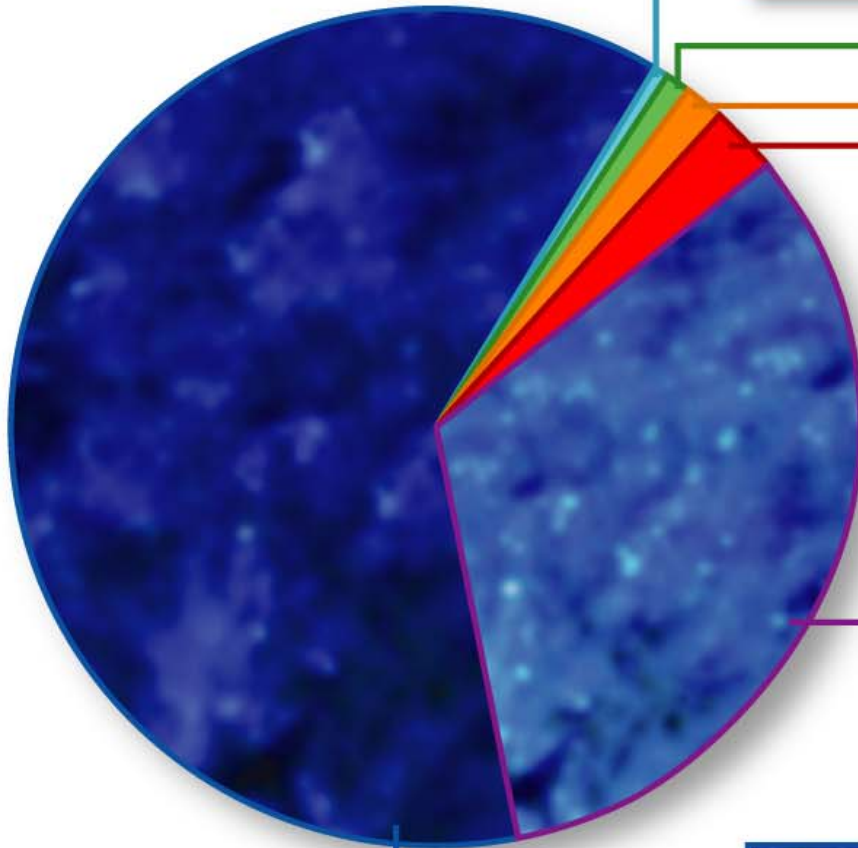


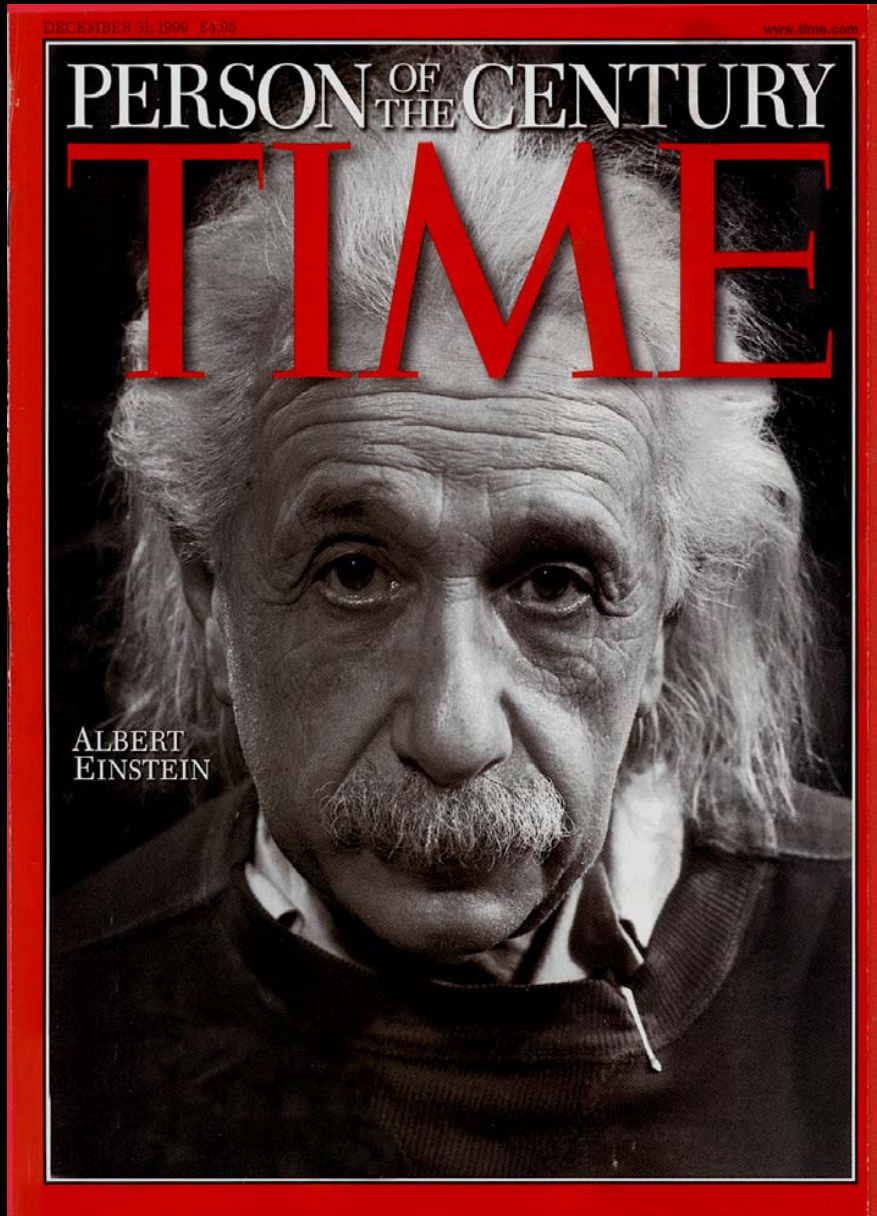
**Dark Matter:
25%**



**Dark Energy:
70%**

***Nothing
matters!***





“The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. Those to whom this emotion is a stranger, . . . are as good as dead; their eyes are closed.”

Albert Einstein

The cosmic food chain (Ω_i)

Massless neutrinos (2) :	0.002%
Photons:	0.005%
Metals:	0.023%
Massive Neutrino (1) $m=0.2$ eV:	0.47 %
Stars:	0.50 %
Dark neutrons & protons:	4. %
Dark matter:	25. %
Dark energy:	70. %

the Neutrinos



Ballard Firehouse

January 26

February 9

\$3.00

The cosmic food chain (Ω_i)

Massless neutrinos (2) :	0.002%
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Much ado about nothing
(the quantum vacuum)

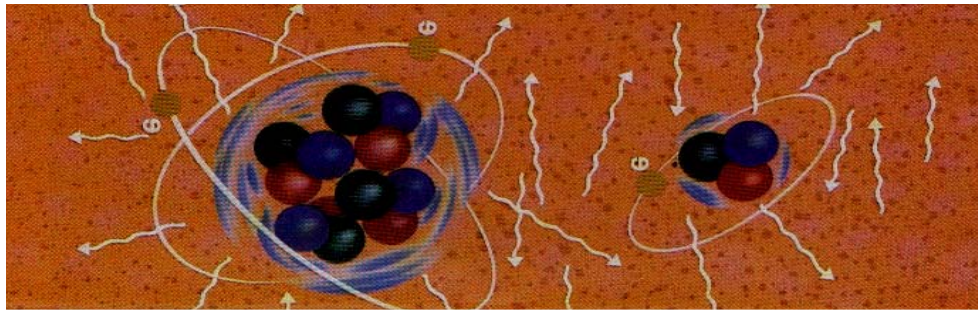
NOTHING is something!

NOTHING has energy!

NOTHING matters!

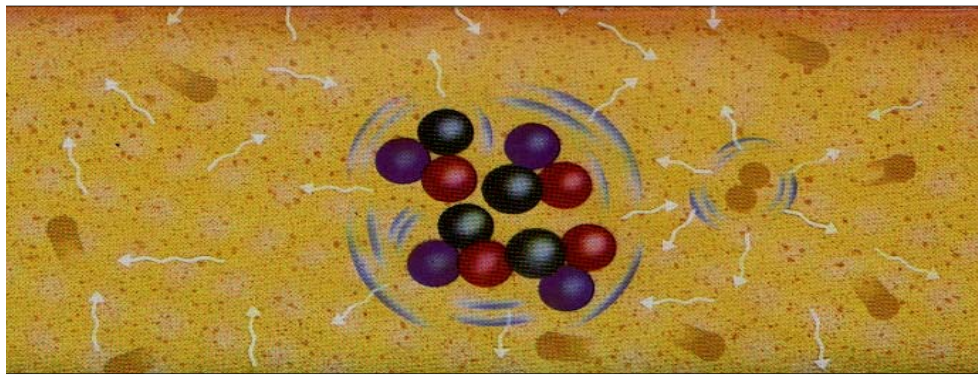
NOTHING changes!

**380,000
years**



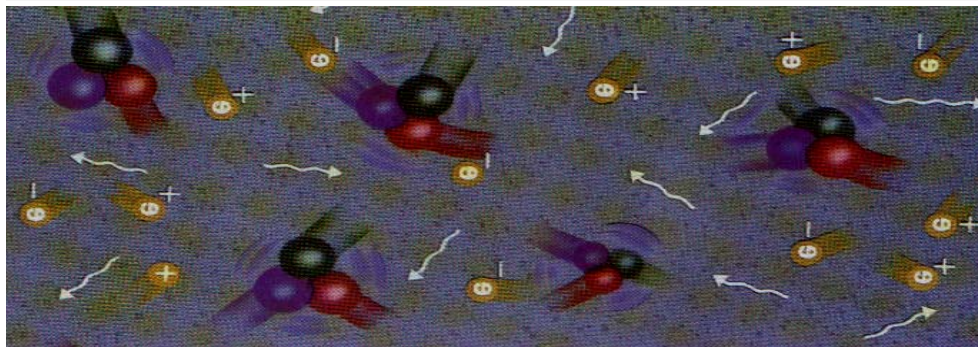
**atoms
form**

**3
minutes**



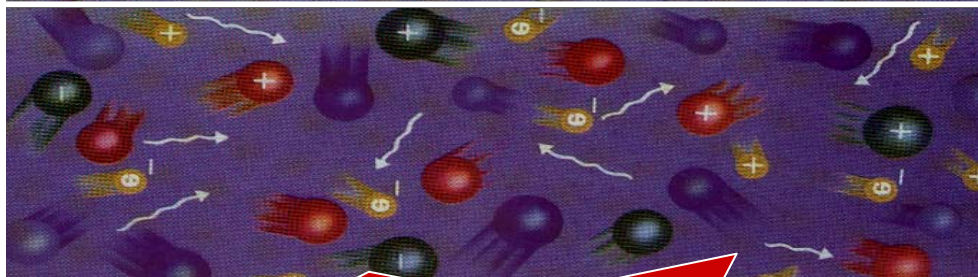
**nuclei
form**

**1-micro
second**



**neutrons
protons
form**

**4-pico
seconds**

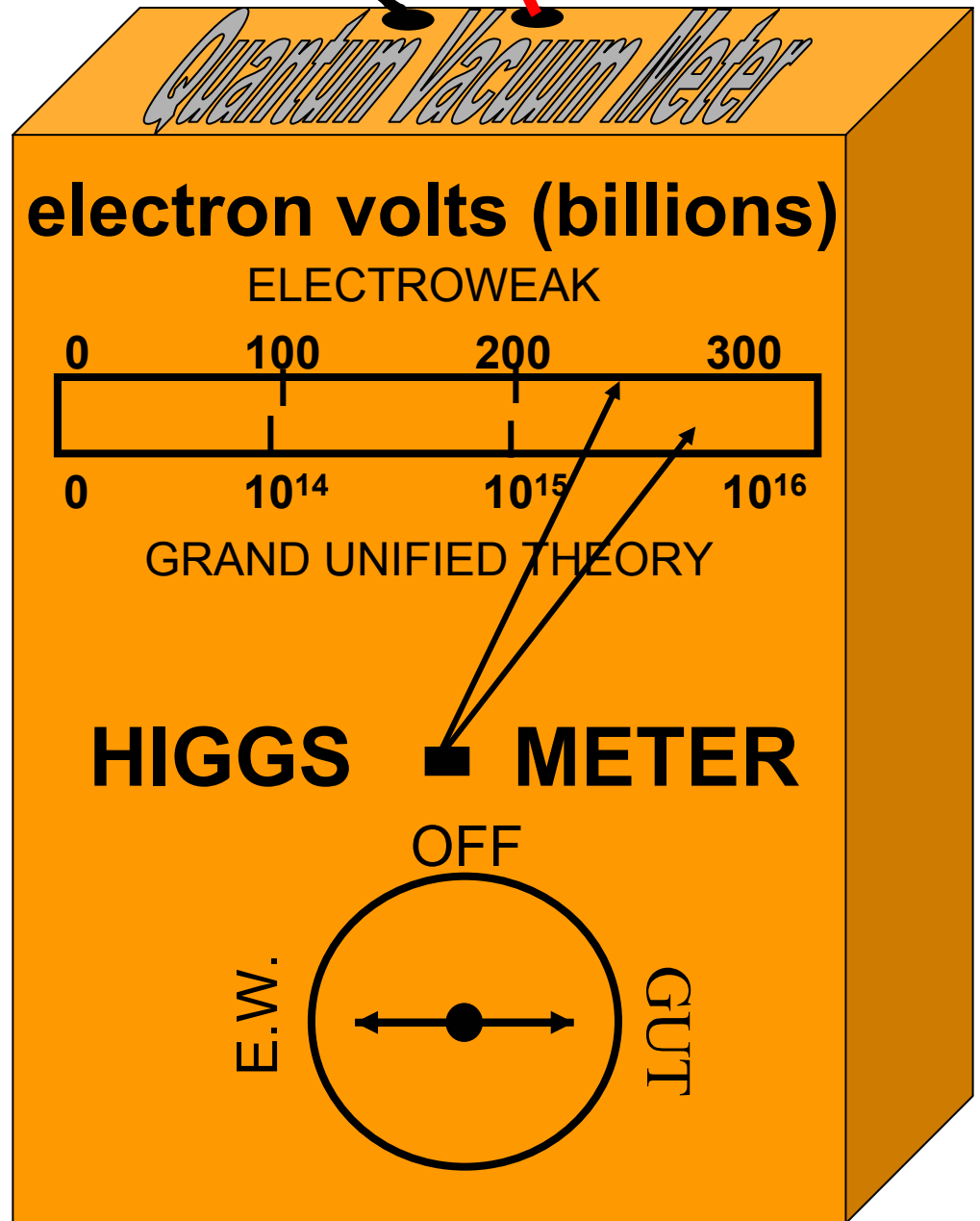


**primordial
soup**

BANG!

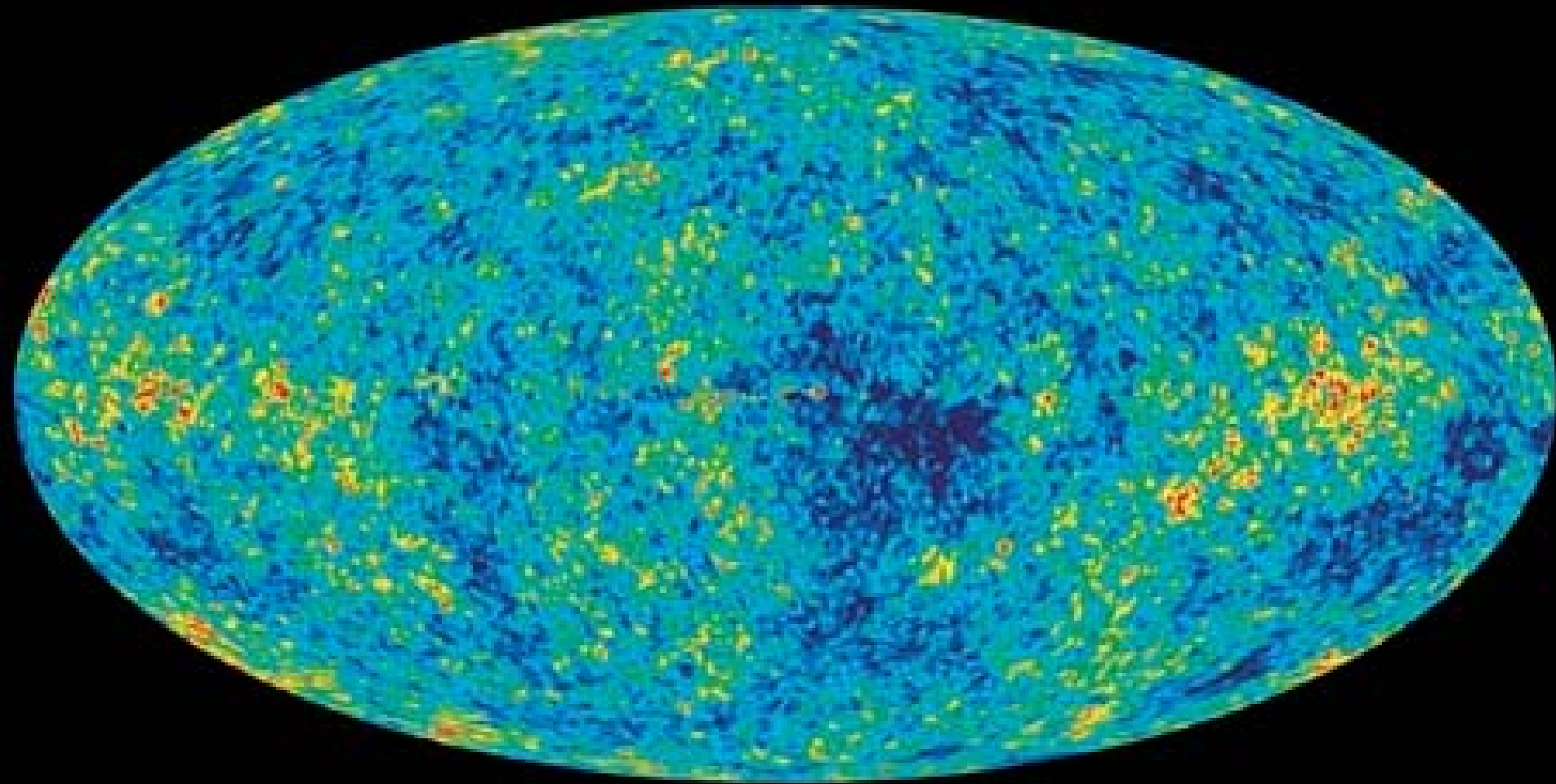
Before primordial soup?

Nothing!



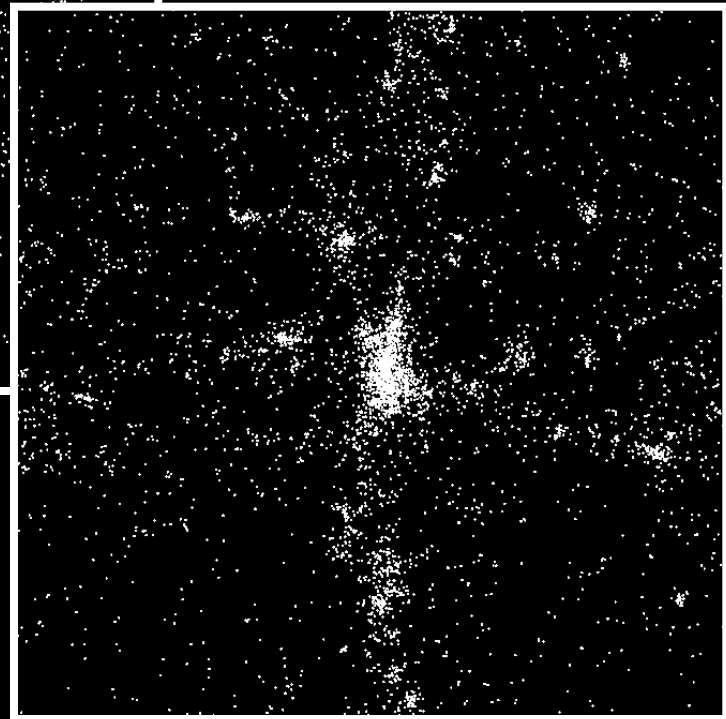
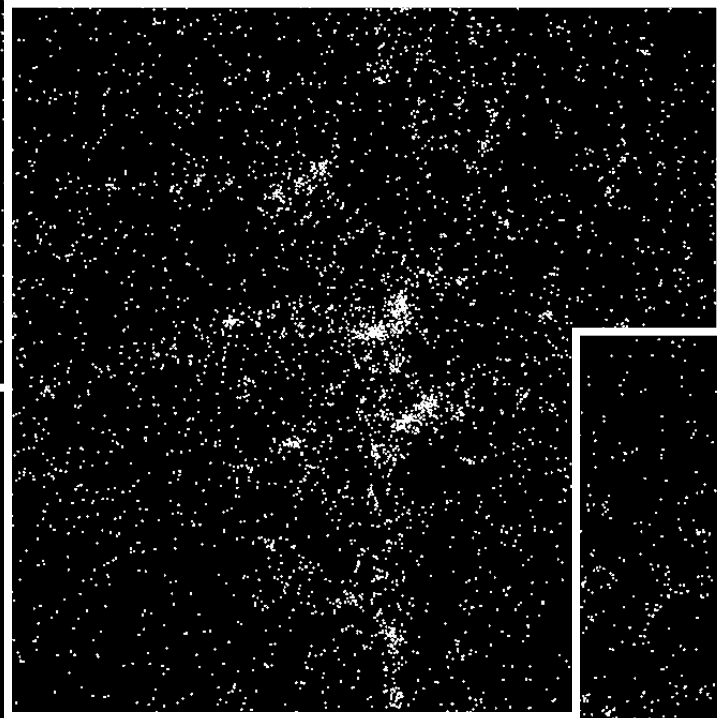
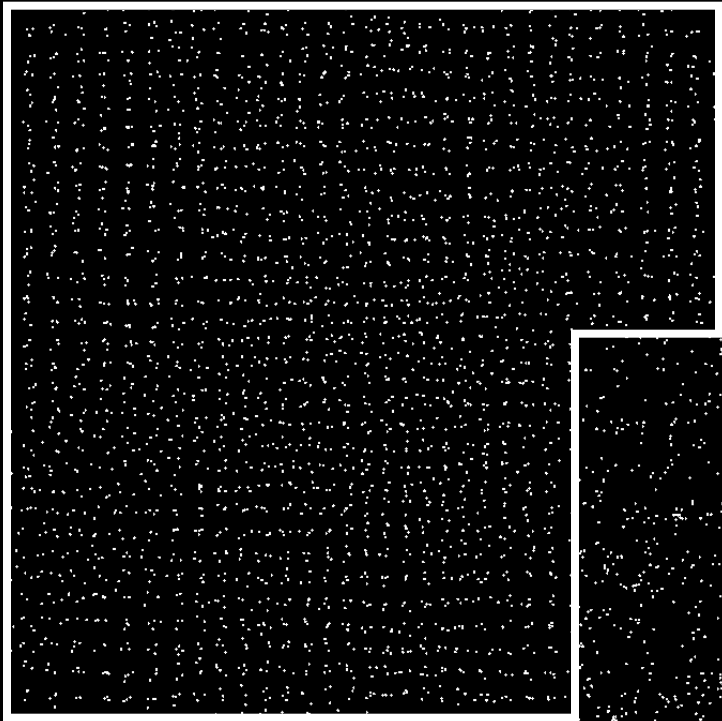
Nothing
can change!

Baby picture of the universe



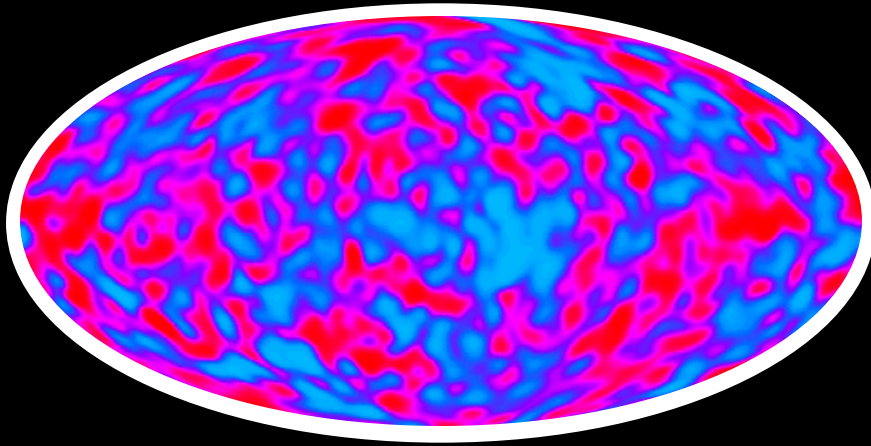
**The universe at 380,000 years old
(1/2 day old for 50-year old)**

Primordial *perturbations*

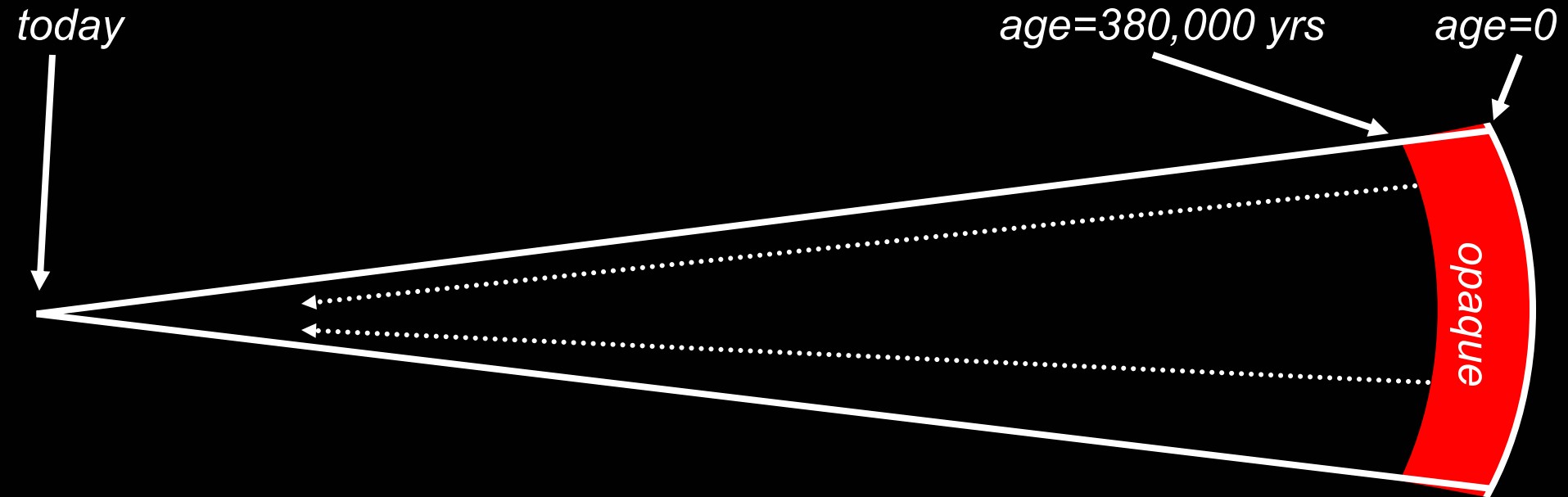


time ↘

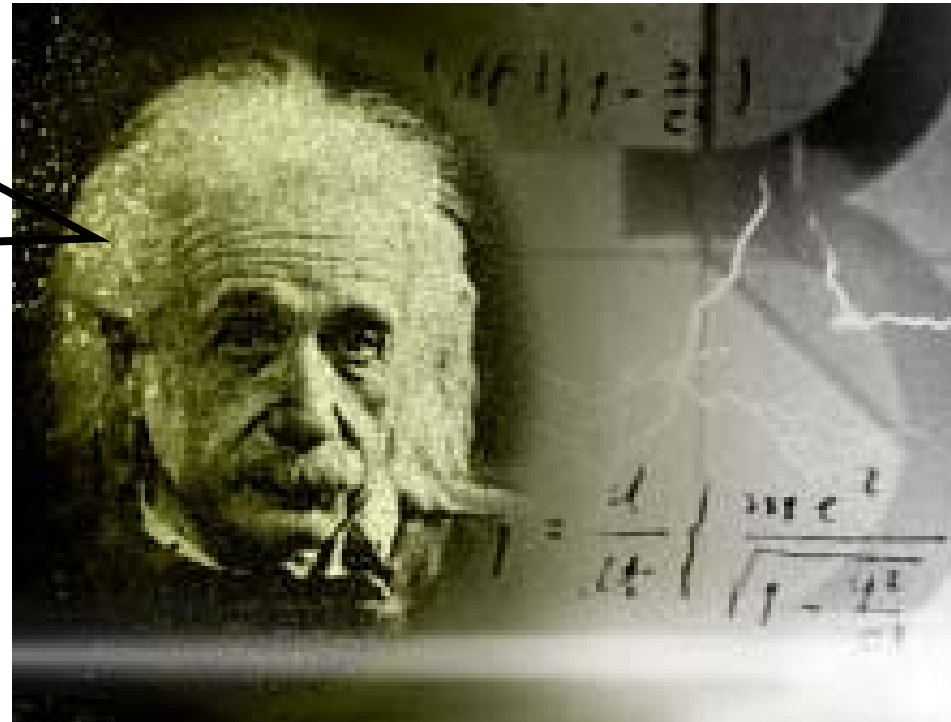
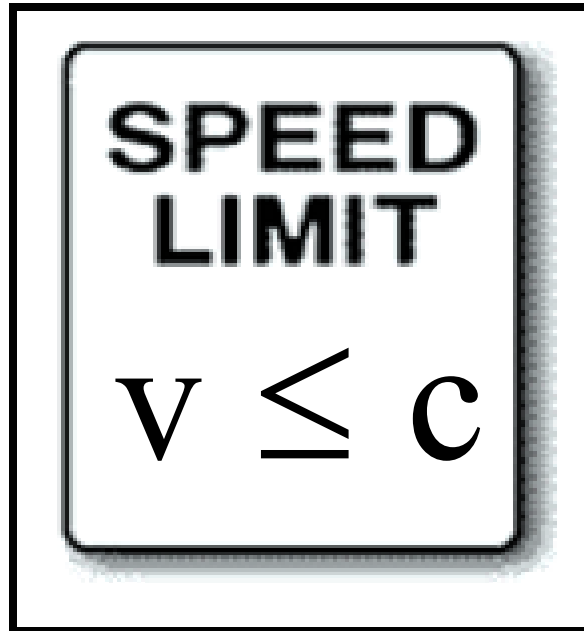
Primordial perturbations



**CBR: a snapshot of the
universe 380,000 years AB**
**correlations on scales
 \gg 380,000 light years**



More than 380,000 light years in less than 380,000 years?



- $v \leq c$ for velocity through space
- no limit on expansion velocity of space
- “acausal” requires “inflation”

Nothing changes!

Today: dark energy (the vacuum, empty space)

0.000 000 000 000 000 000 000 000 000 000 001 g cm⁻³

Inflation: dark energy (the vacuum, empty space)

**1.000 000 000 000 000 000 000 000 000 000 000 000
000 000 000 000 000 000 000 000 000 000 000 000
000 000 000 000 000 g cm⁻³**

Cosmic Symphony (Harmonice Mundi)

expansion tempo	movement	epoch	relic
pizzicato	string	10^{-43} s?	???
presto	inflation	10^{-35} s?	CBR fluctuations gravitational waves seeds of structure
allegro	radiation	earlier than 10,000 years	abundances of the light elements
andante	matter	later than 10,000 years	growth of structure: galaxies, clusters,...
largo	inflation	day before yesterday	acceleration of the universe